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THE EMPIRICAL STABILITY EVALUATION OF THE KÖRÜKINI CAVE, DEREBUCAK, KONYA

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Highlights

- The Körükini cave is one of the most important caves of the Derebucak area (Konya, Türkiye).
- The empirical method was applied to the cave for evaluation its stability.
- Collapses may occur in the Körükini Cave and support is recommended.

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ABSTRACT: Located 145 km away from Konya, the Körükini cave is one of the most important caves of the Derebucak area. In this study, it is aimed to evaluate the stability of the Körükini cave. For this purpose, we conducted geological field trips, took block samples and made in-situ field tests. Following these steps, we applied laboratory tests to determine physico-mechanical properties on rock samples taken from the cave.

Based on the RMR, GSI, Q, RMi classification, rock mass values were determined for the Körükini Cave. Thus, average RMR is 60, average Q is 8.2, average GSI is 75 and average RMi 11.64. the obtained data show that the Körükini Cave is unstable in all locations according to empirical stability evaluation. Thus, support (e.g. systematic bolting, fibre reinforced shotcrete and bolting, and fibre reinforced shotcrete and bolting) is needed for the Körükini Cave.

Keywords: *Karstic Derebucak Caves, Stability, Empirical, Rock Mass Classification.*

1. INTRODUCTION

Located 145 km away from Konya, the Körükini cave is one of the most important caves of the Derebucak area (Figure 1). The entry of the Körükini cave is 1340 m height above sea level (Figure 2). The height of the entry is 30 m. There are eroded rock fragments with equal size in the passage and a deep lake 130 m ahead. There are also exits from the cave with more than 12x12 m size and a lot of stalactite and stalagmite. The cave has increasingly attracted visitors in the last years.

About 30% of Turkey is covered with carbonate rocks. Taurus Karst Belt, Southeast Anatolian Karst Belt, Northwest Anatolian Karst Belt and Konya Closed Basin Karst Belt are the most common [1]. The extensive limestone outcrops and thicknesses in Turkey facilitated the formation of caves.

Caves are classified in different ways according to their formation, development, physico-chemical structures and cover thickness. In general, underground cavities can be artificial or natural according to their formation, caves are among the natural formations. There are many artificial caves in our country, especially in the Taurus belt. Artificial caves are mostly created for shelter, storage, burial and mining purposes [2-3]. Natural caves, on the other hand, are formed as a result of the erosion of soluble rocks by natural processes. In natural caves, cave formation may occur during the formation of the main rock (such as travertine cavities, lava and glacial caves). In addition, secondary (karstic) caves can be formed by the effect of water from rocks such as soluble limestone, gypsum, etc. [4]. There are approximately 35,000 to 40,000 karst caves in Turkey, most of which are located in the Taurus Mountain Belt [5-6].

In this study, it is aimed to evaluate the stability of the Körükini cave, based on the empirical method that is mainly for the man-made engineering structures (e.g. tunnel, slope etc.). For this purpose, we conducted geological field trips, took block samples and made in-situ field tests. Following these steps, we applied laboratory tests to determine physico-mechanical properties on rock samples taken from the cave.

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2. GENERAL GEOLOGY

The study area is located on the Anatolide-Tauride block, which formed as an extensive carbonate platform during the Mesozoic and was intensely deformed and partly metamorphosed during Alpide orogeny [7].

The oldest unit in the study area is Early to Middle Cambrian autochthon carbonates which are mostly recrystallized and dolomitized. The Cretaceous Peridotite and ophiolitic melange are observed above the carbonates. The Jurassic to Cretaceous allochthon units composed of neritic carbonates exist in the South of the study area. They have thickness with more than 10 m, which is suitable for cave formation and karst structure such as karren, doline etc. Plio-Quaternary units unconformably overlie all the older units in the study area (Figure 1).

3. MATERIAL AND METHODS

Field observations and many measurements were done on layerings and joints to determine strike and dip both in and outside the Körükini cave. A Schmidt hammer was used in the field to indirectly determine uniaxial compressive strength. Block samples were taken from both inside and outside of the cave, and mechanical tests were done on these samples in the rock mechanics laboratory in the Konya Technical University. Core samples were taken from the rock blocks using NX-type core barrel, and they were cut and polished according to the ISRM [8-9].

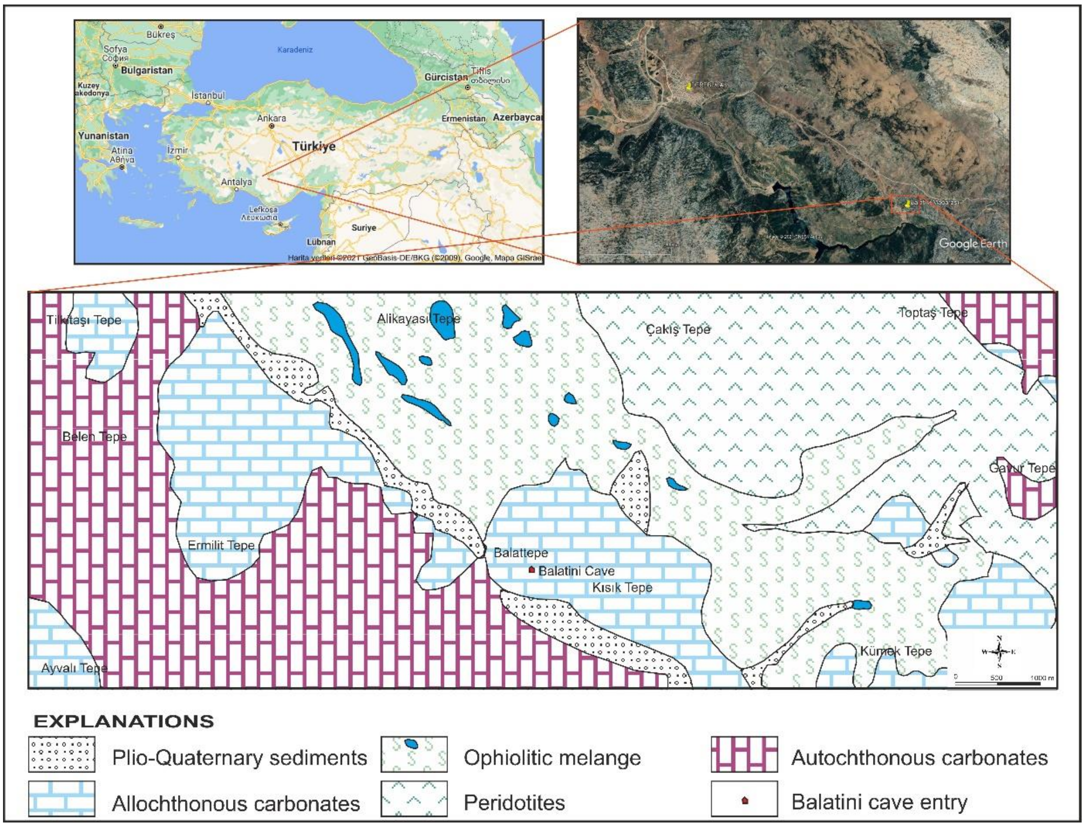


Figure 1. Simplified geological map of the Körükini cave and its surroundings [10]

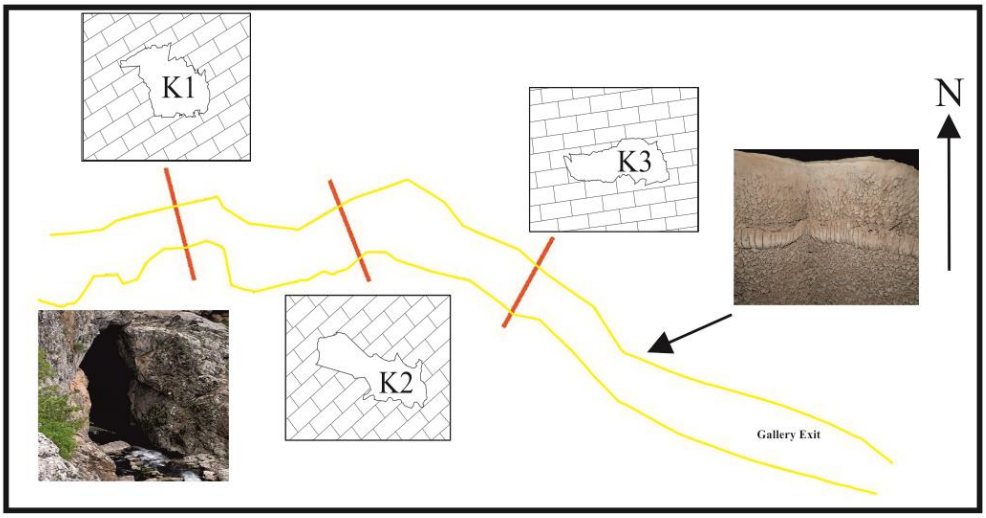
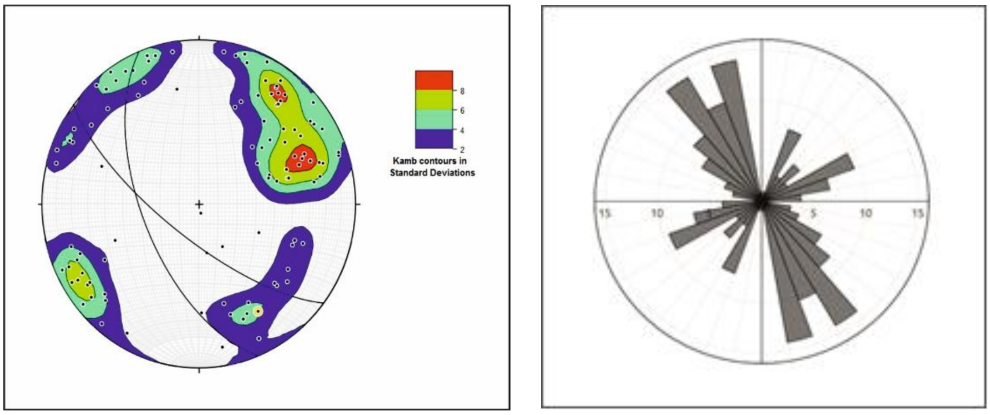


Figure 2. Plan and sections of Körükini cave

3.1. Status of Discontinuities around the Körükini Cave

Measurements of strike and dip from discontinuities were evaluated according to the method by Allmendinger [11] and constructed contour and rose diagrams (Figure 3). Thus, two joint sets were determined. Fractures strike NW-SE and dip to SW with 10° to 40° (average 30°). Contour diagrams in Figure 3 clearly show two joint sets. Dominant orientations of the fractures are N24W/60 SW and N53W/72SW. Rose diagram given in Figure 4 shows that their direction is NW-SE.



A B

Figure 3. Contour and rose diagram of joint measurements around the Körükini Cave.

3.2. Schmidt Hammer Test in the Field

According to filling status of the caves, average uniaxial compressive strength of the joint surface are given in Table 1. Thus, this value is σc (MPa): 76

3.3. Determination of JCS and JRC

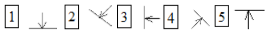
JCS (Joint Wall Compressive Strength) is accepted as 63.5 MPa using the Barton- Bandis [12] sliding criteria for filled or infilled surface of discontinuities in limestone's in the study area (Table 1).

In the field, roughness ranges from 2 to 30, corresponding to JRC (Joint Roughness Coefficient) of 4 to 10 according to the profilometer for the Körükini cave.

Table 1. Schmidt Hardness Test in Field

Name	Fill State	Tilt Angle	Position of the hammer	*Rebound Numbers	**σ_C (MPa)	*σ_C (MPa)
Körükini	Infilled	71°	3	46	77	76
	Filled	65°	4	48	75	

*Average, ** Uniaxial Compressive Strength (from the chart given in the Schmidt Fig.)

*** Position of the hammer, 

3.4. Estimation of RQD

RQD (Rock Quality Designation) is estimated from following equation [13] in the absence of drilling in the field.

RQD = 115 – (3.3 x Jv) (1)

Based on two joint sets meausured from outside the cave, the first and second joint numbers are 47 and 40, respectively and measurement length is 10 m and 9 m., respectively. Thus,

RQD value Jv = (47/10) +(40/9) = 9.14 joint/m2 and RQD = 115-(3.3xJv) = 115-(3.3x9.14) = 85%.

3.5. Uniaxial Compressive Strength Test

This test was made on total 65 core samples according to ISRM [9]. σc was calculated 48.17 MPa for the Körükini cave, pointing to medium strength according to ISRM [8] (Tablo 2).

Tablo 2. Uniaxial compressive strength values of limestone rock samples in the Körükini Cave

	N. No	Diameter D-mm	Length L-mm	Cross- Sectional Area A-m^2	Failure Load P-kN	σc -MPa	UCS $\sigma_{c\,(50)}$ -MPa
Körükini	1	53.73	137,51	0,0022672	119,30	52,62	53,31
	2	53.62	137,51	0,0022577	121,80	53,95	54,63
	3	53.70	137,55	0,0022651	98,50	43,49	44,05
	4	53.65	137,36	0,0022606	91,70	40,56	41,08
	5	53.80	137,91	0,0022735	201,40	88,59	89,76
	6	53.63	137,29	0,0022587	146,00	64,64	65,46
	7	53.66	137,67	0,0022615	110,20	48,73	49,35
	8	53.62	137,41	0,0022577	110,70	49,03	49,65
	9	53.70	137,41	0,0022644	71,60	31,62	32,03
	10	53.72	137,81	0,0022665	116,30	51,31	51,98
	11	53.55	137,59	0,0022522	53,80	23,89	24,18
	12	53.51	137,67	0,0022486	101,70	45,23	45,78
	13	53.73	138,39	0,0022672	92,70	40,89	41,42
	14	53.64	137,51	0,0022594	66,90	29,61	29,99
	15	53.73	138,32	0,0022672	112,10	49,45	50,09
	16	53.75	137,68	0,0022691	108,30	47,73	48,35
	17	53.62	137,29	0,0022579	58,40	25,86	26,19
	18	53.70	137,82	0,0022646	114,50	50,56	51,21
	19	53.73	137,81	0,0022674	124,50	54,91	55,63
	20	53.66	137,71	0,0022615	62,80	27,77	28,12
	21	53.79	137,56	0,0022722	91,70	40,36	40,89
	22	53.75	138,25	0,0022691	182,30	80,34	81,39
	23	53.74	137,09	0,0022680	119,50	52,69	53,38
	Average					**47.56**	**48,17**
	Standard Deviation						**15.87**

4. ROCK MASS CHARACTERISTICS

4.1. RMR

Parameters and values to determine RMR (Rock Mass Rating) for the Körükini Cave are given Table 3. Thus, RMR point ranges from 53 to 71.

4.2. Q System

Q (or Norwegian Geotechnical Institute) value of the Körükini cave is calculated according to the parameters in Table 4. Thus, “the best value” is (RQD for 90); Q= (90/4) (1.5/1) (1/2.5) = 13.5 and “the worst value” is (RQD for 75); Q= (75/4) (1/2) (0.3/3) = 0.93.

4.3. GSI

For Late Cretaceous limestone from the Körükini cave, GSI (Geological Strength Index) was calculated as 75. Rock mass of the limestone has two joint sets with undisturbed.

4.4. RMi

Joint Length (jL) was taken 2 because joint width is from 0.1 to 1 m [14]. Block volume was found from Figure 6 and RMio value is 22 and 25 for jC 1.75. According to equation “Rock Mass Index (RMi = RMio*σc/100)”, RMi_{min} = 22*41.85/100 = 9.20 and RMi_{max} = 25*70.41/100 = 17.60.

Tablo 3. Input parameters to RMR system in Körükini Cave

A. Parameter			
1.	**Strength of intact rock material (σ_c)**	50-100 MPa (76MPa)	
	Rating	7	
2.	**Drill core quality, RQD**	75- 90% (85%)	
	Rating	17	
3.	**Spacing of discontinuities**	200- 600 mm	
	Rating	10	
4.	**Ground water**	WET	DRY
	Puan	7	15
B. Condition of discon- tinuities			
Length, persistence		1- 3 m	**<1** m
Rating		4	6
Separation		>5mm	1-5 mm
Rating		0	1
Roughness		slightly rough	rough
Rating		3	5
Infilling (gouge)		Soft filling <5 mm	Hard filling <5 mm
Rating		2	4
Weathering		moderately w	unweathered
Rating		3	6
RMR (min.):		**53**	
RMR (max):		**71**	
RMR (avg):		**62**	

Tablo 4. Input parameters to Q system in Körükini Cave

Parameter	Rating
1. Rock quality designation (RQD	**RQD**
Good	75%-90% (85%)
2. Joint set number (Jn)	**Jn**
Two joint sets	4
Two joint sets plus random	6
3. Joint roughness number	**Jr**
Smooth, planar	1.0
Rough or irregular, planar	1.5
4. Joint alteration number)	**Ja**
No coating or filling, except from staining (rust)	1.0
Non-softening mineral coatings, clay-free particles, etc.	2.0
5. Joint water reduction factor	**Jw**
Dry excavations or minor inflow, i.e. < 5 l/min locally	1.0
Medium inflow or pressure, occasional outwash of joint fillings	0.66
Large inflow or high pressure in competent rock with unfilled joints	0.5
Large inflow or high pressure, considerable outwash of joint fillings	0.33
6. Stress reduction factor	**SRF**
Low stress, near surface, open joints.	2.5

5. EVALUATION OF EMPIRICAL STABILITY

The minimum width of the Körükini Cave is 6.4 m. According to the RMR classification, maximum unsupported span and stand up time values were given in Figure 4.

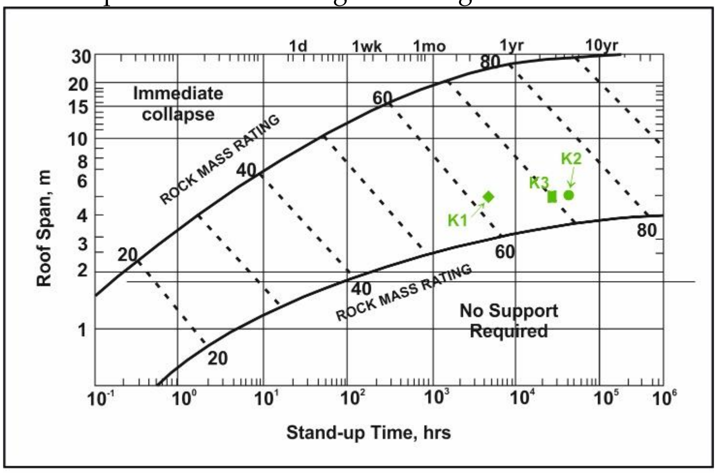


Figure 4. Classification and support recommendations based on RMR-values

RMR points of the Körükini Cave range from 53 to 71, the minimum opening was accepted as 5.4 m. According to Figure 5, sudden collapse may be where opening is more than 15 m. Based on the criteria by Bieniawski [15], stand up time is from 4 to 7 month. According to Figure 5, support system for the Körükini cave are (1) systematic bolting (and unreinforced shotcrete, 4-10 cm), (2) fibre reinforced shotcrete and bolting 5-9 and (3) fibre reinforced shotcrete and bolting 9-12 cm.

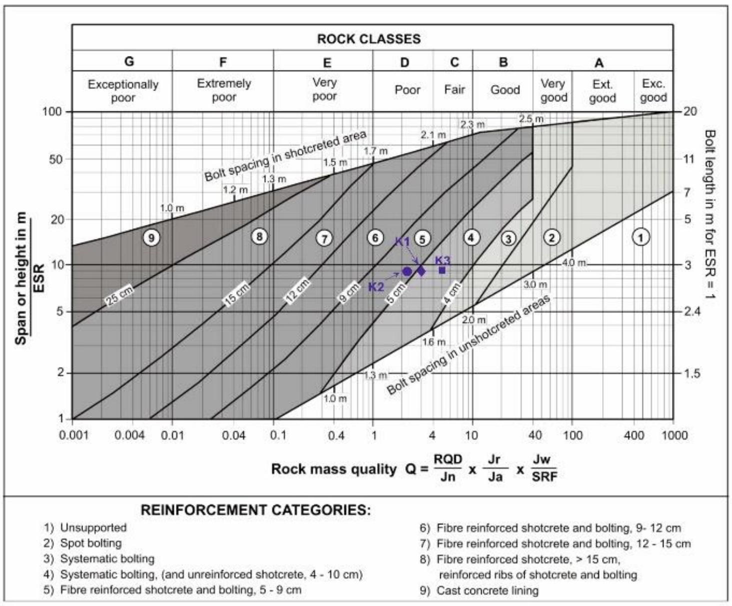


Figure 5. Classification and support recommendations based on Q-values

According to Palmström [14], support type for the Körükini Cave is “shotcrete and rock bolt” with concrete thickness between 40 and 80 mm. when the size ratio (Sr) linearly reduce, rock bolt spacing ranges from 1.7 to 3 m (Figure 6). Based on the evaluation of Empirical stability, support is needed for the Körükini Cave.

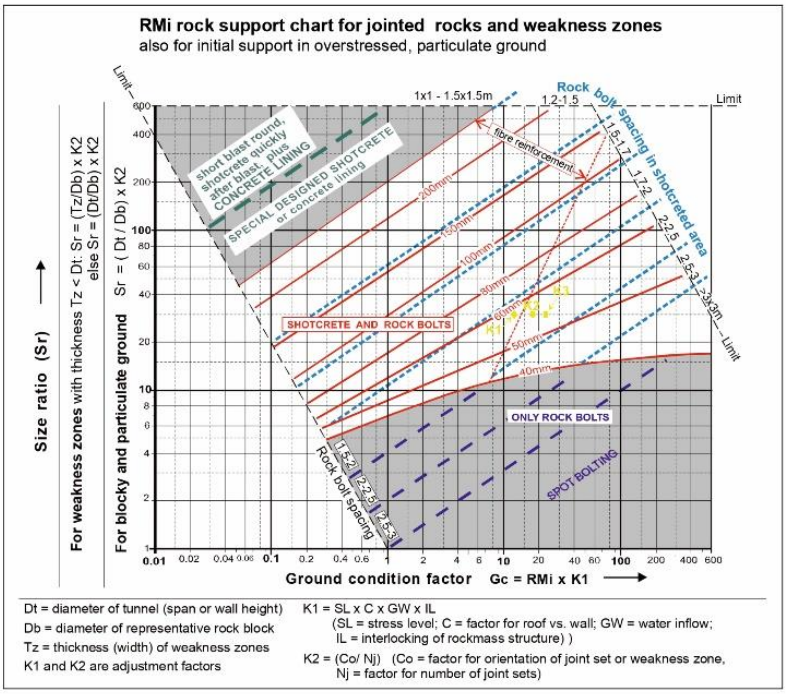


Figure 6. The RMi charts for estimates of rock support in Körükini Cave

6. CONCLUSIONS

In this study, evaluation of Empirical stability was made for the Körükini Cave. Based on the RMR, GSI, Q and RMi systems applied to the Körükini Cave, following conclusions may be reached.

1. Block fall/sliding and collapse are potential risk in the Körükini cave

2. Movement in the hole is higher than those of the entry in the Cave.
3. Support is needed for the Körükini Cave.
4. Blasting should not be allowed around the Körükini Cave.
5. Dynamic condition should be considered in the future studies, because stability evaluation is made under static condition in this study.

Credit Authorship Contribution Statement

Material preparation, data collection and analysis were performed by Ali Ferat BAYRAM and Naji Saleh AL-QUBALI.

Declaration of Competing Interest

The authors declare they have no competing interests

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